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FOR

**Method For Manufacturing Optical Waveguide Using Laser Direct Writing Method and Optical Waveguide
Manufactured by Using the Same**

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METHOD FOR MANUFACTURING OPTICAL WAVEGUIDE USING LASER DIRECT WRITING METHOD AND OPTICAL WAVEGUIDE MANUFACTURED BY USING THE SAME

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a method for manufacturing an optical waveguide by a direct writing method and the optical waveguide manufactured by using the same, and more particularly, to a method of improving a refractive index profile of the optical waveguide by overlapping two or more beams using a Gaussian laser. Also, the present invention provides a method for manufacturing the optical waveguide which is capable of improving waveguide characteristics such as offset structure of a S-bend type optical waveguide and an asymmetrical curved optical waveguide by individually adjusting each of the overlapped laser beams, independently.

DESCRIPTION OF THE PRIOR ART

The method for manufacturing the optical waveguide using the laser direct writing method has the procedure of focusing the laser beam on a photo-sensitive polymer in order to pass through a writing process and increasing the refractive index of the written pattern to form the optical waveguide.

Up to now, an optical device and an optical component has been developed based on semiconductor material and inorganic silica system

material for the purpose of implementing high speed of an optical communication, mass communication. But, recently, polymer material is the concerned about more and more, because it has merits such as a low cost and a simple process.

5 Various methods for manufacturing the optical waveguide have been used using the polymer material, and, in general, there are a photolithography method, a hot embossing method, a direct ultraviolet patterning method, and a laser direct writing method.

10 The photolithography method includes very complicate processes such as a step of coating a cladding material on a substrate, a step of baking, a step of coating a core material, a step of applying a photoresist, a step of exposing using a photomask, a step of developing and a step of etching.

15 In the hot embossing method, a core portion structure is molded in under clad material using a mold master, core material is inserted into the molded structure, an over clad is covered thereon, and ultraviolet rays are irradiated in order to cure the core material and adhere the over clad thereto.

20 In the ultraviolet direct patterning method, after a under clad is formed on a plane substrate, ultraviolet cured polymer is coated thereon as a core layer. And, after exposed to the ultraviolet ray by using the photomask, a core pattern is formed by using a polymer developer and then upper clad material is coated.

The laser direct writing method is based on a laser micro-machining technique. Fig. 1 is a concept diagram illustrating a general laser direct writing method. The light from the laser passes through a tunable neutral

density filter and a shutter and is irradiated on the substrate through the objective lens of a microscope. On the substrate, the clad material is coated and then the core layer is coated. By simple process of focusing the laser beam on the core layer and writing a desired pattern, the optical waveguide
5 can be manufactured. The refractive index of the pattern written by the laser becomes larger than that of the adjacent area, which is not written, and, the optical waveguide, therefore, is formed through total reflection principle.

The laser direct writing method has advantages in shortening of the process time, low cost and the application to large area, because of the simple
10 process without the photomask.

However, in case the optical waveguide is implemented through the laser direct writing method according to prior art, it is difficult to implement a sharpness in boundary (between core material and clad material) of the optical waveguide, because of the nature of the light. The laser beam in the laser
15 writing process has Gaussian distribution, the step profile of the core in the optical waveguide is not clearly formed. As a method for improving the step-like index profile of the optical waveguide, there is the laser direct writing method using a donut-shaped beam (TEM_{01} mode). As a method for generating the donut-shaped beam, a diffracting phase mask or a hologram
20 (CGH: Computer Generated Hologram) has been used.

Since the laser irradiates a light beam with a Gaussian distribution, the step profile of the optical waveguide is not clearly formed. It is why an additional bending loss in the curved region of the optical waveguide is caused.

SUMMARY OF THE INVENTION

Thus, in order to solve the above-mentioned problems, the object of the present invention is to provide a method of improving the refractive index profile of the optical waveguide, in the method for manufacturing the optical waveguide by using the laser direct writing method.

The another object of the present invention is to provide a method of improving the refractive index profile of the optical waveguide without an additional device such as the diffracting phase mask or the hologram in the donut mode beam, by overlapping two or more Gaussian beams to manufacture the optical waveguide.

The another object of the present invention is to provide a method of reducing a bending loss in the curved region of the optical waveguide through asymmetrical overlapping beams and a method for manufacturing a S-bending type optical waveguide having an offset structure.

In order to accomplish the above-mentioned object, one aspect of the present invention provides a method for manufacturing an optical waveguide using a laser direct writing method, comprising coating clad material on a substrate; coating photo-sensitive polymer on said clad material as a core layer; and forming the optical waveguide using a laser beam having Gaussian distribution, wherein the step of forming the optical waveguide includes the step of overlapping at least two laser beams.

Each of at least two laser beams overlapped in the laser direct writing method can be formed by varying at least one of the beam's size, the beam's intensity and writing speed. The refractive index profile of the optical

waveguide can be asymmetrical.

The optical waveguide is formed in a bending structure, and, in the overlapped beam of said bending structure, the refractive index of the beam positioned at the outside is larger than that of the beam positioned at the other
5 area.

Preferably, the number of said laser beams is two, the size and distance thereof is a few μm .

In addition, the step of overlapping at least two laser beams can comprise the steps of forming a first bending-shaped optical waveguide by
10 using a first laser beam, and forming second bending-shaped optical waveguide by a second laser beam so as to be formed cross each other on any one surface of said first optical waveguide on the basis of the center of the bending curve of said formed first optical waveguide.

The other aspect of the present invention provides optical waveguide
15 formed by a laser direct writing method comprising a substrate; clad material coated on said substrate; and photo-sensitive polymer coated on said clad material as a core layer, wherein the refractive index profile of said core layer has a structure manufactured by overlapping at least two laser beams having Gaussian type intensity distribution at a predetermined distance.

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BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a concept diagram illustrating a direct writing method.

Fig. 2A is a photograph of a Gaussian beam, Fig. 2B is a photograph of a donut-shaped beam, and Fig. 2C is a photograph of an overlapped

Gaussian beam.

Figs. 3A and 3B are concept diagrams comparing a single Gaussian beam according to prior art with an overlapped Gaussian beam according to the present invention.

5 Fig. 4 is a graph illustrating energy distributions which optical waveguides are subjected by the single Gaussian beam, the donut-shaped beam, and the overlapped Gaussian beam in a computer simulation.

Fig. 5 is a graph illustrating bending losses of a curved optical waveguide with a rotation of 45 degree with respect to the single Gaussian
10 beam, the donut-shaped beam (TEM₀₁ mode beam), and the overlapped Gaussian beam.

Figs. 6A and 6B illustrate an example that two Gaussian beams are overlapped and the beam has weight different from each other at the inside and the outside thereof.

15 Fig. 7 is a graph illustrating the bending loss due to the overlapped beam having weight different from each other at the inside and the outside thereof.

Fig. 8 illustrates an offset structure according to the preferred embodiment of the present invention.

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DESCRIPTION OF THE PREPERRED EMBODIMENTS

Hereinafter, the embodiments of the present invention will be explained with reference to the accompanying drawings. However, the embodiment of the present invention can be changed into a various type, and it

should be not understood that the scope of the present invention is limit to the following embodiments. The embodiments of the present invention are provided in order to explain the present invention to those skilled in the art.

In manufacturing the optical waveguide, a clad material is coated on the plane substrate, and the photo-sensitive polymer is coated thereon as the core layer. For laser direct writing process, the laser beam is focused and irradiated on the core layer material and the size of the beam is adjusted to a desired size. The stage of substrate is moved to write the pattern of the optical waveguide. Alternatively, the laser beam may be moved. The refractive index of the exposed pattern becomes larger than that of the material, which not exposed, the optical waveguide is formed through the total reflection principle.

In the present invention, the method for overlapping two or more beams to manufacture the optical waveguide is provided such that the refractive index profile of the core in the optical waveguide has a step-like index profile.

The laser direct writing method using the overlapped beams has an advantage in the refractive index of the optical waveguide can be controlled without the additional device such as the phase mask or the hologram in the donut-shaped beam.

In Fig. 2, various kinds of the beam modes used in manufacturing the optical waveguide are shown. Fig. 2A is a photograph of Gaussian beam, Fig. 2B is a photograph of a donut-shaped beam, and Fig. 2C is a photograph of an overlapped Gaussian beam.

The refractive index profile in the core of the optical waveguide is determined in accordance with total amount of the energy which the photo-sensitive material receives in a specific point, and, in detail, it can be obtained by integrating the intensity distribution of the beam in the writing process with respect to the propagating direction of the beam.

Figs. 3A and 3B are concept diagrams comparing a single Gaussian beam according to the prior art with the overlapped Gaussian beam according to the present invention.

The formation of the core of the optical waveguide in the laser direct writing process varies according to laser beam's size, laser beam's intensity, and writing speed, and the variation of the refractive index is generally determined by a total exposure amount irradiated on the core region. These can be expressed with two equations as follows:

$$N_{\text{core}} = n_{\text{clad}} + \Delta n(x) \quad (1)$$

$$\Delta n(x) \approx C_0 \int_{-\sqrt{r^2-x^2}}^{\sqrt{r^2-x^2}} \exp \frac{-2(x^2+z^2)}{r^2} \quad (2)$$

Here, C_0 is a constant determined by a characteristics of written material and writing speed.

Fig. 4 is a graph illustrating a energy distribution in optical waveguides of the signal Gaussian beam, the donut-shaped beam and the overlapped Gaussian beam in a computer simulation, respectively. Since the variation in the refractive index of the photo-sensitive polymer has a linearity before the saturation area of the refractive index, the energy distribution in

which the optical waveguide has a shape similar to the shape of the refractive index variation. Therefore, by adjusting the beam size and the distance between the overlapped Gaussian beams, the profile of the border of the core in the optical waveguide can be implemented in the shape similar to the step shape than the shape, which is implemented by the donut-shaped beam.

In the computer simulation in Fig. 4, the graph of the single Gaussian beam shows the refractive index profile in the optical waveguide, which is formed with the single Gaussian beam having a diameter of $6\mu\text{m}$. The graph of the TEM_{01} mode shows a case using the donut-shaped beam (TEM_{01} mode) in order to improve the refractive index profile of the optical waveguide according to the prior art. In addition, the line graph consisting circular dots shows a case of writing the pattern by overlapping the Gaussian beams, having a diameter of $2.4\mu\text{m}$, spaced a distance of $3.6\mu\text{m}$ apart each other. The line graph consisting inverted triangles shows a case of writing the pattern by overlapping the single Gaussian beams having diameter of $3\mu\text{m}$ at distances of $3.3\mu\text{m}$.

As seen from Fig. 4, the refractive index profile in the optical waveguide generated by the overlapped beams has the shape similar to the step shape, in comparison with the single Gaussian beam, and the size of the beam and the distance between the beams can be adjusted as needed. In particular, the Gaussian beam having diameter of $3\mu\text{m}$, overlapped at distances of $3.3\mu\text{m}$, has a improvement in comparison with the donut-shaped beam. On the other hand, in case of fine-tuning the diameter and the distance, the effect can be improved. Furthermore, the change in the number of the

overlapped beams brings about improvement in effect.

Next, the bending loss in case of using the overlapped Gaussian beam of the present invention is explained.

To compare the bending loss in each case, the bending loss of the
5 curved optical waveguide with a rotation of 45 degree with respect to the TEM_{01} and the overlapped Gaussian beam were calculated. Observing the computer simulation condition, the refractive index in the clad area of the optical waveguide is supposed to be 1.5 and Δn_{\max} is fixed to be 0.01125. The bending loss of the optical waveguide after a rotation of 45 degree is
10 calculated using BPM (Beam Propagation Method). At a result, the larger the size of the beam is, the smaller the bending loss is. The bending losses were calculated in each case, that is to say, the optical waveguide of single beam, the optical waveguide of the overlapped beam and the optical waveguide of the donut mode TEM_{01} beam, which is known to form the
15 border surface of the optical waveguide sharply. Fig. 5 is a graph illustrating the bending loss of the curved optical waveguide with a rotation of 45 degree with respect to the donut mode TEM_{01} beam and the overlapped Gaussian beam. The overlapped beam and the donut-shaped beam have bending loss similar to each other and have the improved bending loss, compared with that
20 of the optical waveguide of the single beam.

Next, the optical waveguide device has an improved waveguide performance by adjusting the size and the intensity of the overlapped beam of the optical waveguide, individually. The bending loss is reduced by increasing the difference between the refractive indexes at the outside of the

curve area in the optical waveguide and the optical waveguide device can be implemented by adjusting the overlapped beams individually. The present invention provides the method of reducing the bending loss of the optical waveguide by increasing the strength of the laser beam forming the outside of the curve and lowering the writing speed to form the asymmetrical optical waveguide with respect to the propagating direction when manufacturing the curved optical waveguide using the laser direct writing method.

In Figs. 6A and 6B, the two Gaussian beams are overlapped, but the size of the beam at outside is different that of at inside. That is, the bending loss is remarkably improved by overlapping two Gaussian beams with appropriate weight. This result is shown in Fig. 7. Referring to Fig. 7, in case the bending radius R is about $3000\mu\text{m}$, the bending loss of the overlapped beam with different weights is about 0.3dB. But, as shown in Fig. 5, in case where the bending radius R is about $3000\mu\text{m}$, the bending loss of the overlapped beams having same weights is about 1 dB. Accordingly, it is found that the bending loss is improved.

On the other hand, the above-mentioned method is applicable to the offset structure in order to reduce the mode mismatch loss. The offset structure functions as the bending loss of the S-bend type optical waveguide in various kinds of the optical devices such as an optical splitter or an optical directional coupler, and the general offset structure has a arrangement with two optical waveguides crossed each other. However, it is difficult that the laser direct writing method accomplish the shape of the optical waveguide at the starting point and the ending point of the writing process, definitely. In

particular, in the direct writing method, it is difficult to implement the offset structure due to the continuity of the writing process. In order to solve these problems, the overlapped Gaussian beams according to the present invention is used, so that the offset structure can be easily implemented.

5 The offset structure of this method is shown in Fig. 8. The first beam is written into a first optical waveguide. The second beams are written into a second optical waveguide in order to have a bending-shaped with two portions. The two portions of second optical waveguide are formed in each side of the first optical waveguide, crossed each other with respect to the center of the
10 bending curve of the first optical waveguide. The second writing beams can be adjusted, individually, to acquire the asymmetrical optical waveguide.

Although the present invention has been illustrated and described with respect to exemplary embodiments thereof, the present invention should not be understood as limited to the specific embodiment, and it should be understood
15 by those skilled in the art that the foregoing and various other changes, omission and additions may be made therein and thereto, without departing from the spirit and scope of the present invention.

As mentioned above, the present invention can provide the method for improving the refractive index profile using the overlapped beam in the laser
20 direct writing method and the method for improving the bending loss of the curved optical waveguide.

In addition, it is applicable to devices such as an optical directional coupler, an optical splitter, an optical switch by using the offset structure of an S-bend type optical waveguide and an asymmetrical optical waveguide

manufactured by the overlapped beams.